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Competition effect on innovation and productivity - The Portuguese case[23]

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Abstract

The aim of the present paper is to assess the effect of competition on innovation (patent applications) and on productivity (Total Factor Productivity and Labour Productivity), using data from 654 Portuguese firms, according to 208 NACE 4-digits sectors, and over the period 2007 to 2015. For this purpose, two different methodological approaches were used, a Poisson regression model for the patent function and a log-log fixed effect model for the productivity function. The results reveal that, on average, competition has a negative, U-shaped form effect on innovation in the short term, and a positive effect in the medium-long term. Nevertheless, the model focusing only on manufacturing sectors shows some differences from the model considering all economic activities, namely a linear positive effect of competition on innovation. Concerning the effect of competition on productivity, a positive effect on Total Factor Productivity emerged from the analysis, while for labour productivity a negative one prevails.

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1. Introduction

Competition refers to a rivalry process between individuals, groups, firms or nations, aiming to achieve a specific objective. In the business context, the object of rivalry is e.g. sales, profits, market share or corporate control, and the instruments used in this attempt for market power could be e.g. price, improved product or service quality, patenting or cost reduction (Vickers, 1995). Competition is considered a key driver to enhance consumer welfare and efficient allocation of resources, because it forces firms to react in order to become more efficient and able to offer a greater choice of products and services at lower prices (OECD, 1993). From this definition of competition two main concepts emerge: i) innovation which is connected with the introduction of new or improved products or services in the market, and can be measured e.g. through research and development (R&D) activity or the patenting process; ii) productivity which is linked with cost reduction, economies of scale and lower prices.

The relationship between competition and innovation or with productivity has been studied in recent decades by many authors (for a survey of the literature see e.g. Symeonidis, 1996; Gilbert, 2006; Holmes and Smitz, 2010). Nevertheless, there is no consensus as to the direction of the effect. While some defended the existence of an inverted U-shaped relationship, due to escaping the competition and the Schumpeterian effect, such as Aghion et al. (2005), others defended a monotonic impact (e.g. Arrow, 1962; Correa and Ornaghi, 2014).

The objective of this paper is to contribute to the literature and to assess the effect of competition on innovation strategy (patent applications) and on productivity, based on 654 Portuguese firms. The present empirical study intends to answer the following research questions: How do Portuguese firms react to competition pressure? Can competition lead to an increase in innovation performance and firm productivity in Portugal?

The methodological approach is based on a Poisson regression model for the patent function and a log-log fixed effect model for the productivity function. Competition will be measured through a profitability index following the framework of Aghion et al. (2005).

The originality and contribution of this study lies in two main aspects. Firstly, few studies assess this relationship between competition and firm performance in Portuguese firms. Secondly, better understanding of this phenomenon could help policy-makers to improve public intervention in the market and help them upgrade public policies supporting firm competition, innovation and performance.

The paper is structured in five sections. After the introduction, section 2 presents the different measures for quantifying competition in the market, as well as a brief description of the main findings about the effect of competition on innovation and productivity. Section 3 describes the data and methodological approach. Section 4 presents the empirical results. Section 5 reports the conclusion.

2. Background theory [24]

2.1. Measuring competition

Market power and market share are the two main measures used in the scientific literature to quantify the level of competition in the market.

Market power refers to firms' ability to control, raise and maintain price above the level that would prevail under (perfect) competition (OECD, 1993). The indicator most commonly used to assess the degree of market power is the Lerner (1934) Index, which corresponds to the ratio of price (P) minus marginal cost (MC) over price (1), where marginal cost refers to the cost of producing one additional unit of product or services.

$$\text{Lerner Index (LI)} = \frac{P - MC}{P} \;;\; where \text{ MC } = \frac{\partial Cost}{\partial Quantity} \qquad (1)$$

A particularity of the LI equation (1) is its similarity to the inverse formula for the elasticity demand, if the marginal cost is replaced by marginal receipts (Lerner, 1934). Since the LI is related to the market

[24] See Appendix A for a summary of the main studies assessed in this section.

price elasticity of demand, it is also able to capture the threat effect of substitute products outside the industry, which means that a firm in a monopoly market facing strong competition from substitute products, could have weak market power or a low LI (Besanko and Braeutigam, 2011:457).

The LI ranges between 0 and 1, where 0 (price = marginal cost) indicates perfect competition and values above 0 some degree of market power. This mean that the higher the index, the lower the level of competition (higher level of market power). Therefore, to have an indicator to assess the inverse relationship – higher values equal to a higher level of competition – it is common to transform it. Authors using the LI as a baseline to measure competition (e.g. Aghion et al., 2005; Okada, 2005; Correa and Ornaghi, 2014) usually estimate an industry-year indicator, and not a firm-year one, using the average value across firms within the industry. In this case, competition measures ($c_{j,t}$) reported in equation (2), where i indexes firm, considers the number of firms (N) in industry j in year t, to estimate the average LI across all firms within an industry j. Values near to 1 indicate a higher level of competition and those close to 0 a higher level of market power.

$$c_{j,t} = 1 - \frac{1}{N_{j,t}} \sum\nolimits_{i \in j} LI_{i,t} \tag{2}$$

Nevertheless, despite its popularity, the LI shows some limitations[25] and difficulties in computation. First, the marginal cost is not directly observed (Correa and Ornaghi, 2014) and it is not easy to measure empirically (OECD, 1993). Alternatively, authors (Okada, 2005; Czarnitzki and Kraft, 2011; Dhanora et al., 2017) have used statistical data about the variable cost, since in the presence of constant returns to scale[26]the LI, when all the variables in (1) are multiplied by the quantities (Q) sold, the index is equal to the ratio of sales less variable cost by sales (3). For example, Dhanora et al. (2017) defined variable cost as the sum of labour cost, electricity cost and raw material, whereas Czarnitzki and Kraft (2011) considered it as the sum of labour, capital and raw material cost.

$$LI = \frac{P - MC}{P} = \frac{Q * P - Q * MC}{Q * P} = \frac{sales - variable\ cost}{sales} \tag{3}$$

A second main restriction of the Index, reported by Lindenberg and Ross (1981), lies in not covering fixed costs, since by definition, in marginal cost only variable costs are considered. To overcome this limitation, and also due to data availability, different alternative measures of LI are utilized for empirical calculation. Lindenberg and Ross (1981) used the ratio of difference between sales less operating expenses to sales. Nickell (1996) and Aghion et al. (2005), as well as Inui et al. (2012) and Correa and Ornaghi (2014), considered operating profit, minus financial cost, divided by sales (4), where financial cost takes into account the amount of capital stock and the cost of capital. The index reported in equation (4) is an approximation to the LI, which Aghion et al. (2005) call price cost margin and Correa and Ornaghi (2014) call the profitability index.

$$Price\ cost\ margin\ or\ Profitability\ index = \pi_{i,t} = \frac{operating\ profit_{i,t} - financial\ cost_{i,t}}{sales_{i,t}} \tag{4}$$

Another way to measure competition is by using the market share, which measures the relative size of a firm in an industry in terms of the proportion of total output (OECD, 1993). The concentration index most commonly used is the Herfindahl (1950) and Hirschman (1945) Index (HHI), which takes into account the number and size of firms in the industry, to estimate their contribution to the total

[25] For a survey about the uses and limitations of the Lerner Index see (Elzinga and Mills, 2011).

[26] One assumption of the Lerner (1934) index is to consider that many firms produce with constant returns to scale and with a marginal cost equal to those firms with a monopoly power (Elzinga and Mills, 2011:558).

activity in this industry[27]. This indicator is expressed in equation (5), where s_i represents the relative measure of the economic activity of the i^{th} firm and n is the total number of firms in the industry. To estimate the HHI, authors (Okada, 2005; Kato, 2009; Inui et al., 2012) generally used firms' sales to quantify their economic activity.

$$HHI = \sum_{i=1}^{n}(s_i)^2, \text{ where } \sum_{i=1}^{n} s_i = 1 \quad (5)$$

The HHI is a concentration index, and like other concentration measures, describes market structure and is a *prima facie* indicator of market power or competition among firms (OECD, 1993). Nevertheless, according to some authors market power indicators have some advantages over market share ones.

Market structure and market concentration do not precisely reflect the nature of competition intensity (Correa and Ornaghi, 2014), particularly when this comes from price influences. Secondly, concentration measures, compared to the price-cost margin, can mislead the analysis of market competition, when the sample includes firms operating in international markets but the data available only includes firms established in a national market (Aghion et al., 2005).

The LI (and its variants) and HHI have in common that the main source of data for estimating them comes from firms' financial statistics. More recently, a new way to measure market power and market share appears using survey data and the entrepreneur's own perception about the competitive environment.

Among questions to which entrepreneurs are asked to give their opinion, studies reported, as a proxy for market share or structure, their opinion about the number of competitors in the market for the main product sold by the firm surveyed (e. g. Carlin et al. 2004; Soames et al., 2011; Friesenbichler and Peneder, 2016; Crowley and Jordan, 2017) or about how easy it is for competitors to enter the market (Tang, 2006). Market power, in turn, is measured by the perception of customer behaviour when the firm surveyed increases the price of its product (Carlin et al. 2004) or competitors' capacity to influence product price (Amin, 2015).

Despite its advantage, providing a new vision of the issue, the main limitations of using the survey data approach are linked with its subjective measure, limited to one period of time (usually cross-sectional analysis) and aggregated level of activity sectors[28].

2.2. The effect of competition on innovation

As summarized by Gilbert (2006) and Im et al. (2015), in the background theory about competition's effect on innovation, four main studies exist, Schumpeter (1934), Arrow (1962), Boone (2001) and Aghion et al. (2005), and all of them present different conclusions.

Schumpeter (1934) defended that despite competition stimulating innovation, this only happens at a low level of competition. According to the author, when competition is high, modest and less efficient innovators are discouraged from innovating, and in the end a negative correlation is found between competition and innovation. Arrow (1962) predicted the opposite (a positive relationship), explaining that in a monopoly situation due to profit maximization criteria, a firm has less incentive to innovate compared to the situation in a competitive environment. So, in this case, firms faced with a high level of competition innovated more to rise above the competitors.

Boone (2001) and Aghion et al. (2005) both supported a non-linear relationship between competition and innovation, but Boone (2001) presented a model leading to a U-shaped relationship and Aghion et al. (2005) found an inverted U-shaped relationship. Aghion et al. (2005), using data from UK stock market listed firms and patents as the output measure of innovation, found that faced with a higher degree of competition in a sector, firms closer to the technology frontier will innovate more in order to escape the competition, whereas firms far from the frontier, and trying to catch up, will be discouraged by this higher degree of competition, and consequently innovate less (Aghion, 2017:11).

[27] The index could be computed on the basis of 1, 1.000 or 10.000, where this extreme value represents a monopoly situation (only one firm).

[28] For example, Crowley and Jordan (2017) only make a distinction between low, medium and high technology industry.

Additionally, Boone (2011) sustained in his theoretical model that despite competition reducing firms' profit, they only react by introducing an innovation, depending on the industry's cost and the value of product market competition. This author explained that, in the presence of a low level of competition less efficient firms are active and consequently the incentive to innovate is lower, since the profit from greater efficiency is still positive and higher than that of competitors. However, when competition becomes more intense and interaction between firms becomes more aggressive, only highly efficient firms are active in the market and the leader is more likely to innovate (Boone, 2001).

Such divergence about the direction of competition has led several researchers and academics to focus their work on trying to confirm or reject the findings of the previously cited authors. For example, following the same empirical framework as Aghion et al. (2015), Correa and Ornaghi (2014) applied the same exercise to US manufacturing firms, but only found a linear positive effect of competition on patents, justifying their findings (absence of an inverted-U relationship) due to the well-defined intellectual property rights in the market.

More recently, as the results of a survey database based on a new type of competition indicators, authors have been trying to find similarities or differences concerning the conclusions of Schumpeter (1934), Arrow (1962), Boone (2001) and Aghion et al. (2005). Some research based on a market structure indicator - n° of competitors - pointed to an inverted-U shaped relationship, using as the innovation measure the type of innovation (Carlin et al., 2004; Crowley and Jordan, 2017) or R&D expenditure (Friesenbichler and Peneder, 2016), whereas other authors found a positive effect of the constant arrival of competing products (Tang, 2006) and market share on the propensity to innovate (Soames et al, 2011). As regards studies based on market power indicators, Carlin et al. (2004) revealed that the ability to raise prices has a positive effect on the decision to innovate, while Soames et al. (2011) reported a negative effect of perception of the price-cost margin. These last authors interpreted their findings, explaining that firms with a smaller margin, due to competition pressure, are more likely to innovate. The study by Tang (2006) also showed a negative effect of market power, measured by easy product substitution, on R&D expenditure and innovation activities.

2.3. The effect of competition on productivity

Concerning the effect of competition on productivity, as for innovation, the findings in the literature are not unanimous, despite a positive relationship prevailing.

Based on UK data, Haskel (1991) found that a high level of market power (or fewer competitors), leads to inefficient work practices and consequently to a low level of productivity, since the concentration ratio falls and rising productivity is observed. Nickell (1996), using both measures of competition, the number of competitors and rent levels, found they had a positive effect on total factor productivity growth for UK firms. Kato (2009), using market share indicators of Indian manufacturing industries, reported a positive effect of HHI on the growth rate of total factor productivity. Similar conclusions were also found by Correa and Ornaghi (2014) for US firms and using a profitability index to measure the level of competition. Even authors using survey data, such as Amin (2015) and Friesenbichler and Peneder (2016), showed the same relationship with indicators linked with the ability to influence product price and number of competitors, respectively.

Carlin et al. (2004) come to different conclusions depending on the indicator used. The results presented in their paper about transition countries only showed a linear positive relationship when competition is measured by market power. When the number of competitors (market share) is used, an inverted U-shaped relationship with productivity growth is revealed. Okada (2005) and Inui et al. (2012), in turn, studying the effect of competition on the Japanese economy, found robust evidence of an inverted-U relation between competition and productivity, but only for firms engaged in R&D activities. Market power and market share indicators are used in both scientific analyses and the conclusions are the same, irrespective of the index employed. The non-linear relationship concerning the impact of competition on productivity was strongly defended by Aghion (2017), due to the positive *escape competition effect* and negative *discouragement effect*.

3. Data and methodology

3.1. Relevant market definition

As the profitability index (4) used by Aghion et al. (2005), Inui et al. (2012) and Correa and Ornaghi (2014) will be used, the first step consists of defining the relevant market of each firm included in the sample. The relevant market should cover all the geographical area where the firm faces constraints from both demand and supply side substitution (OECD, 2012). Two main concepts emerge from this definition: i) the product substitution effect and ii) the geographical influence of producers on customers' decision to buy a product.

Concerning the first dimension, most studies cited in the previous section used the economic activity classification to define substitute products. Nevertheless, a high level of disaggregation should be used to avoid bias and to identify products as close as possible to their substitutes (Amador and Soares, 2013).

As regards the second item, since the firm's market can be at the local, regional, national or international level, knowledge of customers' geographical area of influence is necessary. For example, a small retail store located in the south of Portugal has no competition pressure from a similar shop situated in the north of country at least 400 kilometres away. To include the latter, to assess the former's market power or market share would not be correct, because the relevant market, in this case, is defined at a local level and should include only competitors influencing local customers' choice. Nevertheless, this information is not available on the database used in the present study and consequently the analysis excludes all firms with a potentially relevant market at the local and regional level. Several assumptions have been made based on firm size, economic activity and the number of subsidiaries. Bigger firms and firms with subsidiaries are more likely to have a relevant market beyond the regional level. Also, firms operating in some economic activities are more likely to have only a demand for the product at a local or regional level than others. This is particularly the case for small firms operating in the retail trade and tourism sectors[29] (hotels and restaurants). So, it is important to identify only sectors likely to sell their goods and services at a national and international level. Scientific literature has usually focused on the manufacturing sector (e.g. Okada, 2005; Tang, 2006; Kato, 2009; Inui et al., 2012; Correa and Ornaghi, 2014), because goods produced are easily tradable and transportable among regions and countries. Similarly, support services to firms have the same characteristics, even if the final product, e.g. a report or a design can be sent electronically. The service sector was assessed together with manufacturing industry by Soames et al. (2011).

To sum up, firms included in the present analysis were selected by the following steps. Firstly, all medium and large firms in all activity sectors[30]. Secondly, all firms with more than 1 subsidiary in all activity sectors. Thirdly, micro and small firms in manufacturing industry, construction[31] and service support to firms (specialized, scientific and technical activities; information and communication; administrative and support services activities).

3.2. Data source

The study covers 654 Portuguese firms, between 2007 and 2015, with patent applications at the national and international level from 1956, and included in the economic activities listed previously. This sample represents around 65% of all Portuguese firms with patent applications from 1956[32].

The database comes from several sources. Financial and patent information[33] comes from AMADEUS, a database created by Bureau van Dijk. The list of firms with an R&D tax incentive was taken from the Portuguese tax and customs authority's statistical department. The names of firms receiving public

[29] Usually tourists choose the hotel and restaurant as a function of the place that they want to visit and not the place according to the hotel and restaurant where they will stay and eat.

[30] Aghion et al. (2005) used a sample of stock market firms, which are likely to be bigger.

[31] The construction sector was considered because it is also included in the secondary sector, which corresponds to all economic activities using raw material from the primary sector (Agriculture, livestock production, hunting, forestry and fishing) to transform it in new goods, products or construction.

[32] According to the AMADEUS database, in Portugal, 1.012 firms submitted at least one patent application between 1956 and 2016.

[33] AMADEUS is a source of data for PATSTAT patent statistics, which is in turn a worldwide database.

support for R&D and innovation[34] were extracted from the Information System of the Portuguese National Strategic Reference Framework (NSRF) 2007-2013 Incentive Systems.

3.3. Competition indicator

Following the work of Aghion et al. (2005) and Correa and Ornaghi (2014), the present study used as competition measure ($c_{j,t}$) an index of the average profits in the industry.

$$c_{j,t} = 1 - \frac{1}{N_{j,t}} \sum_{i \in j} \pi_{i,t}; \qquad where\ \pi_{i,t} = \frac{EBIT_{i,t}}{sales_{i,t}} \tag{2}$$

The first step consists of estimating the profitability index ($\pi_{i,t}$) of the most representative firms in the Portuguese economy[35] by NACE code 4-digit. EBIT (Earnings Before Interest and Taxes) is used as an equivalent to "operating profits less financial cost". Taking into account the data available, EBIT seems to be the best proxy, as explained in Table 1. After estimating the average profitability index across all firms for each year, this value is subtracted to one, in order to get an indicator measuring the level of competition (and not the inverse, market power). The competition measure is later attributed to each firm taking their economic activity into account.

TABLE 1. PROFITABILITY INDEX: AGHION ET AL. (2005) VERSUS CORREA AND ORNAGHI (2014)

Authors	Operating profits	Financial cost = capital stock * capital cost
Aghion et al. (2005)	Operating profits net of depreciation and provisions ➔ similar to EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization) if amortization is not taken into account	▪ Capital stock = Perpetual inventory method➔ similar to tangible fixed assets with depreciation and amortization ▪ Capital cost = 8.5% ↳ Financial cost is similar to amortization cost
Correa and Ornaghi (2014)	Operating Income Before Depreciation ➔ similar to EBITDA (earnings before interest, taxes, depreciation, and amortization)	▪ Capital stock = Total Gross Property, Plant and Equipment ➔ similar to tangible fixed assets without depreciation and amortization ▪ Capital cost = 8.5% ↳ Financial cost is similar to amortization cost
Operating profits less financial cost is similar to EBIT (Earnings Before Interest and Taxes) = EBITDA less depreciation and Amortization		

Source: Authors' own elaboration based on Aghion et al. (2005) and Correa and Ornaghi (2014).

3.4. Methodological framework

As the aim of the present study is to assess the effect of competition on innovation and on productivity and since the competition indicators used were defined above, the present section provides information about the dependent variables, explanatory variables and econometrics used.

Innovation will be measured through patent application and productivity using two indicators: Total Factor Productivity (TFP), estimated through a Cobb-Douglas production function[36], and Labour Productivity (LP), which is equal to the ratio between value added and number of employees.

[34] Through the following incentive systems of the Portuguese National Strategic Reference Framework (NSRF) 2007-2013:**SI** I&DT – incentive system for technology research and development in companies, SI Innovation – innovation incentive system and SI Qualification SME – incentive system for the qualification and internationalization of SMEs.

[35] AMADEUS database lists approximately 292,000 firms operating in the sectors selected for the present study, which have recorded a total amount of sales above €291,230 million. The most representative firms (around 95,593) are those with annual sales higher than €100.000 which accounts for 92% of the total sales of the sectors under analysis.

[36] For more details about Cobb-Douglas production function see Appendix B2.

The first model, which assesses the effect of competition on innovation, used a count data model, namely a Poisson regression model, because the dependent variable only assumes non-negative integer values $\{0, 1, 2, 3, 4, 5, \dots\}$. Indeed, linear regression model could be inconsistent or inefficient when used with count outcomes (Long and Freese, 2014). The Poisson regression model is reported in equation (6) where $\mu_{i,t}$ is the expected outcome given a random variable $y_{i,t}$ (number of patent applications of firm i during the period t) and a set of explanatory variables $x_{i,t}$. The Poisson regression model (6) takes an exponential form and consequently $\mu_{i,t}$ assumes only positive value, which is needed because $y_{i,t}$ is only equal to zero or positive.

$$\mu_{i,t} = E(y_{i,t}|x_{i,t}) = \exp(x_{i,t}\beta) \quad (6)$$

Additionally to competition level, the explanatory variables include in the model (6) is based on those commonly used in the scientific literature about patent and innovation decision[37], namely:

- Past innovative performance, measured through the growth rate of patent stock per employee, where the stock is estimated using the perpetual inventory method[38];
- Firm size measured by the number of employees (Scherer, 1965; Crépon *et al.*, 1998);
- Qualification of human resources (Beneito *et al.*, 2014), which in this model is measured by the labour cost per employee because this indicator is positively correlated with the education and competence of the workforce.
- Firm age (Beneito *et al.*, 2014);
- Access to public support (Tang, 2006; Chan, 2010; Rizzo and Ramaciotti, 2014), measured through R&D tax incentive, R&D grants, subsidized loans and grants for innovation. A dummy variable was created assuming the value of 1 if the firm received any kind of direct or indirect public support to R&D or innovation (RDI). A distinction between the differences policy tools is not performed because it is not the target of the present study.

As regards the second model, once the dependent variable assumes continuous values a linear regression model (7) will be used, namely random-effects (RE) and fixed-effects model (FE). Both equations are indexed to firm i under the period t, and contain the error term $\varepsilon_{i,t}$ composed by a time-invariant component α_i and an idiosyncratic error term $u_{i,t}$.

$$y_{i,t} = \beta_0 + x_{i,t}\beta + \varepsilon_{i,t} \text{ , where } \varepsilon_{i,t} = \alpha_i + u_{i,t} \quad (7)$$

The set of independent variables $(x_{i,t})$ explaining the dependent variable $y_{i,t}$ (productivity level expressed in logarithm) includes, in addition to competition level, those commonly used in the scientific literature[39], namely:

- Firm size (Crépon *et al.*, 1998). Firm size was divided in four categories (micro, small, medium and large-sized firms) taking into account the criteria number of employees, as reported in the Commission Recommendation 2003/361**;**
- Qualification of human resources (Crépon *et al.*, 1998), which in this model is measured by the labour cost per employee, expressed in logarithm form;
- Stock of patent applications per employee (Crépon *et al.*, 1998), lagged one period;
- Physical capital per employee (Crépon *et al.*, 1998), measured by tangible fixed assets per employee expressed in logarithm form and lagged one period;
- Access to public support (Sissoko, 2011), measured through R&D tax incentive, R&D grants, subsidized loans and grants for innovation.

All monetary variables include in equation (6) and (7) are expressed in thousands of euro and constant price (base = 2007).

[37] See also Table A1 in Appendix A.
[38] For more details about patent stock estimation see Appendix B1.
[39] See also Table A1 in Appendix A.

4. Results and discussion

4.1. Data description

The database covers 654 firms, between 2007 and 2015, divided into 208 NACE 4-digits sectors and more aggregated 16 sectors. The panel is unbalanced because information for some explanatory variables is missing for some years.

The sample is mainly composed of small and medium-sized enterprises (SME) and by firms more than 10 years old (Table B1 – Appendix B). Firms assessed are mostly concentrated in the NUTS 2 level regions of Norte (41.3%), Centro (30%) and Lisboa (24.6%), where firm density is also higher. The average number of patent applications between 2007 and 2015 was 0.48 per year, with a minimum of zero and a maximum of 134.

Despite the study covering a vast range of economic activity, firms operating in manufacturing industry represent more than 66% of the sample, followed by specialized, scientific and technical activities accounting for around 15% of the total (Table 2). These two sections also register the highest proportion of patent applications (86.5% of the total).

Table 2. Patent versus competition level, by main economic activity

SECTION	N. Firms		N° Patent		Patent by firm		Competition level	
	Total	% Total	Total	% Total	Average	Ranking	Average	Ranking
C. Manufacturing industry	429	65.6%	1 902	67.3%	4.4	3	0.9374	2
F. Construction	22	3.4%	41	1.5%	1.9	7	0.9337	3
G. Trade, repair of automobiles and motorcycles	26	4.0%	80	2.8%	3.1	4	0.9470	1
J. Information and communication	41	6.3%	112	4.0%	2.7	5	0.9043	5
M. Specialized, scientific and technical activities	96	14.7%	543	19.2%	5.7	1	0.8868	6
N. Administrative and support services activities	18	2.8%	97	3.4%	5.4	2	0.9117	4
Other sectors	22	3.4%	52	1.8%	2.4	6	0.8554	7
TOTAL	654		2827		4.3			

Source: Authors' own elaboration based on AMADEUS database.

Note: Other sectors included firms in the following sections: A. Agriculture, Forestry and Fishing; B. Extractive industries; D. Production and distribution of electricity, gas, steam and air conditioning; E. Production and distribution of water, sanitation, waste management and depollution; H. Transport and storage; I. Accommodation and restoration; K. Financial and insurance activities; L. Real estate activities; P. Teaching and; Q. Human health and social action.

As regards the competition level indicator, the lowest average value reported in Table 2 is found in the "others" sectors, which included a group of firms operating in sectors with the lowest competition or the highest concentration of market power. This group also reports lower innovation performance (average patents *per* firm). On the other hand, "Specialized, scientific and technical activities" also report low competition, but show the highest innovation performance. In turn, manufacturing industry records a high degree of competition and relatively high innovation performance. This interpretation could suggest a positive or negative relationship depending on the economic activity.

Concerning the productivity level of the sample, Table 3 reports the average value per firm-year for both measures, TFP and Labour Productivity (LP). A first interesting conclusion is that some economic activities do not rank equally in performance depending on the indicator used. For example, manufacturing industry and construction activities showed a higher relative performance when measured by TFP than by LP, whereas for specialized, scientific and technical activities (section M) and administrative and support services activities (section N) higher relative performance is shown with LP.

TABLE 3. PRODUCTIVITY *VERSUS* COMPETITION, BY MAIN ECONOMIC ACTIVITY

SECTION	Competition level		TFP		Labour Productivity	
	Average firm-year	Ranking	Average firm-year	Ranking	Average firm-year	Ranking
C. Manufacturing industry	0.9374	2	7.14	3	37	6
F. Construction	0.9337	3	7.00	4	33	7
G. Trade, repair of automobiles and motorcycles	0.9470	1	7.29	2	200	2
J. Information and communication	0.9043	5	6.24	5	38	5
M. Specialized, scientific and technical activities	0.8868	6	5.45	7	99	3
N. Administrative and support services activities	0.9117	4	5.98	6	45	4
Other sectors	0.8554	7	8.77	1	759	1

Source: Authors' own elaboration based on AMADEUS database.
Note: Other sectors included firms in the following sections: A. Agriculture, Forestry and Fishing; B. Extractive industries; D. Production and distribution of electricity, gas, steam and air conditioning; E. Production and distribution of water, sanitation, waste management and depollution; H. Transport and storage; I. Accommodation and restoration; K. Financial and insurance activities; L. Real estate activities; P. Teaching and; Q. Human health and social action
TFP = Total Factor Productivity. Labour productivity = valued added by employee.

Table 3 also reveals different behaviours as regards the relationship between competition and productivity:

- Sector with a low level of competition shows a higher performance (others sector);
- Sectors with a high level of competition are associated with high (section G) or modest (section J) performance;
- Sectors with a high level of competition have high performance in TFP and a low performance in LP (section C and F);
- Sectors with low (section M) or modest (section N) competition are linked with low performance in TFP and modest performance in LP.

So once again, the relationship between competition and productivity seems to depend on the sector and the variable used in the analysis.

4.2. Results of patent model

Starting with a simple Poisson regression estimation, with competition level and fixed effects for year, economic activity and NUTS 2 regional level, the results reported in Table D1 (Appendix D) show a negative, non-linear, U-shaped relationship between competition level and innovation, as predicted by Boone (2001). Nevertheless, when the effect of competition is assessed taking into account its growth rate, a positive relationship is found. These findings mean that, in the short-term, the direct effect of competition is negative, but in the medium-long term it becomes dynamic since, faced with increased competition in the market, firms are forced to innovate to overcome competition pressure. Furthermore, these conclusions are seen to be robust since when adding a control variable to the previous baseline model they remain the same, using either a random-effects or a conditional fixed-effects estimator (Table 4).

TABLE 4. RESULTS OF POISSON REGRESSION – N° OF PATENT APPLICATIONS, ALL SECTORS

Variables	Random Effects Model 1	Fixed effects Model 2	Random effects Model 3	Fixed effects Model 4	Random effects Model 5	Fixed effects Model 6
Competition level	-85.19***	-93.61***	-87.14**	-96.33***	-	-
	(32.48)	(32.04)	(33.88)	(34.38)	-	-
Competition level (squared)	49.31***	55.22***	50.37**	56.74***	-	-
	(18.71)	(18.66)	(19.80)	(20.26)	-	-
Δ Competition level (growth rate)	-	-	-	-	5.545**	5.958***
	-	-	-	-	(2.156)	(2.072)
Firm size - Log (n° employee)	0.469***	0.998***	0.479***	0.991***	0.467***	0.961***
	(0.113)	(0.248)	(0.117)	(0.257)	(0.106)	(0.243)
Firm age - Log (n° year)	-0.686***	-0.631**	-0.662***	-0.544*	-0.649***	-0.483
	(0.118)	(0.313)	(0.119)	(0.329)	(0.121)	(0.340)
Δ Patent stock per employee	0.494**	0.549**	0.502**	0.555**	0.478**	0.532**
	(0.208)	(0.262)	(0.223)	(0.279)	(0.217)	(0.260)
Log (average salary per employee) - "T-1"	0.379*	0.403	0.364*	0.353	0.342*	0.308
	(0.196)	(0.403)	(0.197)	(0.402)	(0.184)	(0.360)
Received national public support for RDI - "T"	0.415***	0.383***	-	-	-	-
	(0.113)	(0.125)	-	-	-	-
Received national public support for RDI - "T-1"	-	-	0.224**	0.174*	0.234**	0.191**
	-	-	(0.0994)	(0.0944)	(0.0951)	(0.0925)
NACE 2 digits dummy	YES	NO	YES	NO	YES	NO
Region dummy	YES	NO	YES	NO	YES	NO
Year dummy	YES	YES	YES	YES	YES	YES
Constant	35.64***	-	36.46***	-	-0.176	-
	(13.39)	-	(13.81)	-	(0.460)	-
Observations	4,782	2,609	4,782	2,609	4,782	2,609
Number of id	654	361	654	361	654	361
Log pseudolikelihood	-33,917.01	-21,449.18	-3.410,33	-2.161,17	-3.416,00	-2.168,18
H0: All coefficient = 0	0,0000	0.0000	0,0000	0,0000	0,0000	0,0000
LR test of alpha=0	0,0000	-	0,0000	-	0,0000	-
Hausman test - Ho: difference in coefficients not systematic		0,0000		0,0000		0,0000

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1. When fixed-effects model is reported it refers to conditional fixed-effects. Results of Wald test and Hausman test refer to p-value.

Table 4 shows the results of the random-effects (RE) and conditional fixed-effects (FE) Poisson regression model. The particularity of the FE estimator when using non-linear models is dropping all observations that are not time varying. For the present study, this implies that when FE estimators are used the number of total observations used for running the regressions falls by almost 50%. So, despite the Hausman test rejecting the hypothesis that individual-level effects are adequately modelled by an RE model, the results of both will be assessed. Comparing the impact and significance of variables between RE and FE, we can see that surprisingly, and despite a significant reduction of the number of observations, the conclusions are very similar.

Firm sized, expressed by the number of employees, and past innovation performance, measured by the growth of patent stock per employee, are revealed to have a positive effect on the number of patent applications, in all models. The average salary paid to employees, a proxy for workers' qualifications, also has a positive impact on the dependent variable, but only a significant effect in the RE models.

Having received any kind of public support for innovation or R&D expenditure increases the likelihood of the number of patent applications and this effect is sustainable, since it can be observed both in t and $t-1$. Firm age has a negative effect on the number of patent applications in almost all models, which means that younger firms are more likely to innovate. One justification for this finding could be that innovation is a way for start-ups to enter the market or get a higher market share, when competition is greater.

Additionally, a similar exercise was performed for firms operating in manufacturing industry. The results in Appendix D1 reveal some differences concerning the impact of competition on firms' innovation behaviour. First, there is a linear and positive correlation between both variables, which is in line with the findings of Correa and Ornaghi (2014) for US manufacturing industry. Secondly, a robust effect of competition growth rate was not found, which means that the effect of competition on innovation in this sector only happens in the short-term.

4.3. Results of productivity model

Now, turning to assessment of competition's effect on productivity, a preliminary analysis based on a simple panel regression with only these two variables (Appendix E) reveals some evidence of a negative effect on labour productivity and a positive one on TFP. Indeed, competition only has a significant and positive effect on TFP when expressed in growth rate and lagged one year, which means the effect is not immediate (it takes at least one year) and firms react only when competition pressure increases. In turn, the negative effect of competition on labour productivity occurs in both ways, through a direct and immediate impact of the degree of competition and by increased competition. Once again, to assess the robustness of these results, control variables were added and the conclusions about the significance and direction of the effects are the same. Table 5 reports the results of a log-log fixed-effects regression, since the Hausman test rejected the hypothesis that individual-level effects are adequately modelled by an RE model.

Concerning the effect on TFP, since this indicator is linked with technological progress, and the development and implementation of new technology takes time, it is not surprising that its impact was not immediate and was the result of a dynamic process. As regards the negative effect on labour productivity, several factors could explain this result. First, as highlighted by Boone (2001), in the presence of a low level of competition, less efficient firms are active and the incentive to innovate is low, which is also in line with the negative effect found for patent application in the short-term. Secondly, product innovation usually has no effect on labour productivity. In fact, it is process innovation that has a positive effect. In the case of new product development and commercialization, the effect on labour productivity could even be inverse, i.e. negative, because employees need time to adapt their skills for efficient production of the new goods, and during this process productivity can even fall. This justification is also in line with the interpretation of patent stock per employee, as an increase here in the previous period generates a decrease in TFP in the current period.

TABLE 5. RESULTS OF LOG-LOG FIXED-EFFECT REGRESSION – TFP AND LP, ALL SECTORS

	Log (TFP)	Log (TFP)	Log (LP)	Log (LP)
VARIABLES	Model 7	Model 8	Model 9	Model 10
Δ Log (competition level) in "T"	-	-	-1.361**	-1.388**
	-	-	(0.598)	(0.597)
Δ Log (competition level) in "T-1"	0.114***	0.118***	-	
	(0.0405)	(0.0409)	-	
Micro sized-firm	-0.300***	-0.298***	0.430***	0.415***
	(0.0282)	(0.0283)	(0.136)	(0.136)
Small sized-firm	-0.147***	-0.146***	0.126	0.118
	(0.0221)	(0.0223)	(0.0992)	(0.100)
Medium sized-firm	-0.0735***	-0.0731***	0.0771	0.0715
	(0.0160)	(0.0161)	(0.0713)	(0.0718)
Log (average salary per employee) in "T"	-0.0119	-0.0120	0.673***	0.676***
	(0.0168)	(0.0168)	(0.136)	(0.137)
Received national public support for RDI in "T"	0.00584**	-	0.0573***	
	(0.00271)	-	(0.0188)	
Received national public support for RDI in "T-1"	-	0.00798***	-	-0.00648
	-	(0.00249)	-	(0.0174)
Patent stock per employee in "T-1"	-0.0170***	-0.0169***	0.0308	0.0316
	(0.00485)	(0.00487)	(0.0971)	(0.0976)
Log (physical capital per employee) in "T-1"	0.0189***	0.0189***	0.0412	0.0409
	(0.00429)	(0.00430)	(0.0265)	(0.0265)
NACE 2 digits dummy	NO	NO	NO	NO
Region dummy	NO	NO	NO	NO
Year dummy	YES	YES	YES	YES
Constant	2.034***	2.034***	1.214***	1.224***
	(0.0725)	(0.0729)	(0.416)	(0.421)
Observations	4,211	4,211	4,379	4,379
Number of id	651	651	613	613
R-squared (within)	0.290	0.291	0.176	0.175
R-squared (between)	0,8516	0,8521	0,3679	0,3676
R-squared (overall)	0,8205	0,8205	0,3869	0,3851
Wald test - H0: All coefficient = 0	0.000	0.000	0.000	0.000
Hausman test - Ho: difference in coefficients not systematic	0.000	0.000	0.000	0.000

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1. When fixed-effects model is reported it refers to conditional fixed-effects. Results of Wald test and Hausman test refer to p-value. Reference category for firm size is large firm.

Regarding the effect of other explanatory variables on productivity, Table 5 reveals some differences depending on the measure used for productivity. Firm size has a positive effect on TFP and a negative one on LP. This conclusion is in line with sample firms' characteristics, as large firms record a lower LP than SMEs but a higher TFP. As regards the difference in LP, since this indicator is the ratio between firm output and input, we can see in Table C3 (Appendix C) that large firms have increased their input more than their output, both measured by growth rate.

A higher average salary per employee, a proxy of workers' qualifications, has a positive effect but only on LP, while, physical capital per employee, measured by firm investment in the previous period, has only a positive impact on TFP. These conclusions are in line with the definition of both productivity indicators. TFP is linked with technological progress, and is associated with investment, while LP is the result of human capital skills, and is influenced by their performance.

Public support for R&D and innovation has a positive and direct effect on both TFP and LP, but while the effect on LP only happens in the short term, for TFP the impact of this policy tool started even in the previous period and remained one year after. This finding showed some evidence that government support is more sustainable in leveraging technological progress than in increasing human capital performance.

Finally, a similar analysis was made for firms operating in manufacturing industry, but as the results did not show differences they are not reported in the present paper. Nevertheless, they are available on request.

5. Conclusion

The present paper assesses the impact of competition on innovation and productivity, based on 654 Portuguese firms, in the period 2007-2015. Innovation is measured by the number of patent applications and productivity by labour productivity and Total Factor Productivity. Competition is estimated using a profitability index, based on the framework of Aghion et al. (2005).

The study reveals that the level of competition in the Portuguese economy is higher in trade and manufacturing industry and lower in specialized, scientific and technical activities. Specialized services are also those showing the best innovative performance, measured by the average number of patents by firm-year, despite low to moderate productivity performance.

On average, competition was revealed to have a negative, U-shaped effect on innovation in the short term, and a positive effect in the medium-long run. However, firms operating in manufacturing industry seem to react more quickly to competitive pressure compared to the average. Indeed, a linear and positive correlation was found between competition and innovation in this sector, which is in line with the findings of Correa and Ornaghi for US manufacturing industry. Nevertheless, the inverted U-shaped relationship of Aghion et al. (2015) is not confirmed in any case, perhaps due to the different characteristics of the firms studied.

Concerning the effect of competition on productivity, a positive effect on Total Factor Productivity emerged from the analysis, while on labour productivity a negative one prevails.

Bigger and younger firms, as well as those with more qualified personnel and higher innovation performance in the past, are more likely to increase the number of patent applications. Public support for R&D and innovation seems to be effective in leveraging both innovation and productivity.

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Appendix

Appendix A. Benchmarking studies: competition, innovation and productivity

Table A1. Studies' characteristics and main conclusion: competition, innovation and productivity

Authors	Country, period, sector, data and methodology	Measuring competition	Dependent variable	Explanatory variable	Main conclusion
Carlin et al. (2004)	▪ 24 transition countries ▪ 1999 ▪ Agriculture, industry and services sector ▪ Business Environment and Enterprise Performance Survey (BEEP) ▪ Structural equations, OLS and GMM	▪ Market structure: entrepreneur self-perception about the number of competitors in the market for its main product ▪ Market power: entrepreneur self-perception about customer behaviour faced with a 10% increase of product price (switch to rival suppliers' vs continue to buy in similar quantities as previously)	▪ Innovation (Equation 1) ▪ Sales growth per employee (Equation 2)	▪ Equation 1: competition, market growth, access to resources, managerial incentives, firm size ▪ Equation 2: growth of employment, innovation, competition, access to resources, managerial incentives ▪ Industry fixed effects, location (agglomeration fixed effects) and country fixed effects	▪ Results show an inverted U-shaped relationship between competition, measured by the number of competitors, and firm performance, whereas market power reveals a positive effect on productivity growth. ▪ The number of competitors is a weak determinant of the decision to innovate for old firms despite showing the inverted-U form. For new firms, the number of competitors is negatively associated with innovation. ▪ The ability to raise prices (market power) has a positive effect on the decision to innovate.
Aghion et al. (2005)	▪ UK ▪ 1973 – 1994 ▪ All industry sector – 17 two-digit SIC codes ▪ Datastream and NBER patents database ▪ Poisson and linear regression	▪ Lerner index (or price cost margin) = operating profit net of depreciation, provisions and financial cost of capital divided by sales	▪ N° of citation-weighted patents ▪ Technology gap using Total Factor Productivity	▪ Competition ▪ Policy changes and reforms (instrument for competition) ▪ Year and industry fixed effects	▪ Inverted-U shaped impact of competition on innovation (patent) ▪ Technology gap increases with competition ▪ Competition increases the incremental profit from innovation (escape-competition effect) and reduces innovation incentives for laggards (Schumpeterian effect)
Okada (2005)	▪ Japan ▪ 1994 – 2000 ▪ Manufacturing sector (59 industry codes) ▪ Basic Survey of Business Structure and Activities ▪ Dynamic panel estimation (Difference GMM)	▪ Product market competition = price-cost margin = (sales - cost of sales + depreciation - cost of capital) / sales ▪ Market share and diversity index = sales of firm i for its product k in the industry segment or market k ▪ Product market competition = 1 – Industry-averaged price–cost margin	▪ Growth of output (real sales) using production function	▪ R&D stock ▪ technology transaction turnovers divided by sales ▪ Herfindahl index of R&D expenditure ▪ Debt-asset ratio (=financial constraint variable) ▪ Growth rates of both industrial sales and import penetration	▪ Product market competition has a positive effect on productivity growth, whereas the, R&D concentration index has a negative effect (=> spreading R&D expenditure among firms has a positive impact on productivity growth) ▪ Market power has no significant effect on competition in the model with the whole sample and a negative one on those with only R&D performance
Tang (2006)	▪ Canada ▪ 1997 - 1999 ▪ Manufacturing sector with 3-digit NAICS ▪ Statistics Canada Survey of	Entrepreneur self-perception about competitive environment: ▪ Easy substitution of	▪ innovation input (R&D) ▪ innovation output (product and/or process)	▪ Competition perception: i) easy substitution of products; ii) constant arrival of competing products; iii) quick obsolescence of	▪ The relationship between competition and innovation activities can be positive or negative, depending on specific competition perception and innovation activities

	Innovation ▪ Logit and Multinomial logit	products ▪ Constant arrival of competing products ▪ Quick obsolescence of products ▪ Rapid change of production technologies	products; iv) rapid change of production technologies ▪ Public support for R&D (tax credits, grants and venture capital) ▪ Firm size ▪ Industry and firm fixed effect	▪ Easy product substitution is negatively correlated with R&D or product innovation, whereas, constant arrival of competing products and their quick obsolescence shows a positive correlation.

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TABLE A1. STUDIES' CHARACTERISTICS AND MAIN CONCLUSION: COMPETITION, INNOVATION AND PRODUCTIVITY

Authors	Country, period, sector, data and methodology	Measuring competition	Dependent variable	Explanatory variable	Main conclusion
Kato (2009)	▪ India ▪ 1991/92 – 2001/02 ▪ 8 Manufacturing industries sector ▪ Annual Survey of Industries ▪ Fixed effect model and Dynamic panel estimation (Difference GMM)	▪ Index of competition variables composed of the Herfindahl index (HHI), the import ratio of the product market and market share of each firm, where the first two indicators are common to all the firms in the same product market, while the last one is specific to individual firms	▪ Growth rates of total factor productivity	▪ Competition (HHI, import ratio of the product market and market share) ▪ Firm size and age	▪ Product market competition enhances productivity growth rates, since a firm with a smaller market share in a less concentrated market (when competitive pressure is high) is likely to have higher TFP growth rates ▪ Import ratios of product market have a negative effect on the growth rates of TFP, whereas the Herfindahl index has a positive one
Soames et al. (2011)	▪ Australia ▪ 2006-2007 ▪ Manufacturing and services sector (17 division) ▪ Australian Bureau of Statistics Business Characteristics Survey ▪ Binary, Multivariate and Ordered probit models	Entrepreneur self-perception about competitive environment: ▪ Price-cost margin (a measure of mark-up over cost) ▪ Market share ▪ Number of competitors ▪ Being hampered by competition	▪ To have innovation activities (product, process, organizational or marketing) ▪ Degree of novelty and n° of innovations introduced	▪ Competition: market share, n° of competitors and price cost margin and being hampered by competition ▪ Firm characteristics: size, age, export status, export intensity and ownership ▪ Intellectual Property indicator only for ordered probit model ▪ Industry fixed effect	▪ Higher market share, higher n° of competitors and a lower price-cost margin are associated with a higher propensity to innovate ▪ Being hampered by competition has a positive effect on innovation and price cost margin a negative one, suggesting that firms facing profit pressures due to competition and with smaller margins are more likely to innovate ▪ The number of innovation types and the degree of novelty are less sensitive to competition. Only being hampered by competition is statistically significant in both models. Price cost margin is negatively significant but only for the n° of innovations and large market share is only positively significant for the degree of novelty.
Inui et al. (2012)	▪ Japan ▪ 1997 – 2003 ▪ Manufacturing sector ▪ Basic Survey of Business Activities of Enterprises ▪ Fixed effect models with instrumental variables	▪ Lerner index = operating profit less financial costs divided by sales ▪ Herfindahl Index= share of the sales of firm i in industry j at time t in percentage terms	▪ Growth of Total Factor Productivity ▪ Firms' distance from TFP in each industry	▪ Competition ▪ Firm size and age ▪ Foreign ownership ▪ Regulation index, Import ratio and N° of firms (instrument for competition) ▪ Firm, industry and time dummy	▪ Competition has an inverted-U relationship with productivity improvement, but only for firms engaged in R&D activities ▪ Market competition widens the technological gap across firms
Correa and Ornaghi (2014)	▪ US ▪ 1974–2001 ▪ Manufacturing industry - four-digit SIC code industries ▪ NBER patents	▪ Profitability = operating profits less capital cost divided by sales	▪ N° of patents (or citation-weighted patents) ▪ Total Factor Productivity (TFP) or	▪ Competition ▪ Technological progress in France and Germany (instrument for competition) = Growth of TFP or	▪ Patent counts (simple or weighted by citations) and productivity (TFP or LP) increases with more competition ▪ Some doubts exist about an inverted-U relationship

	database and U.S. Bureau of Labor Statistics ▪ Negative binomial regression	Labour productivity (LP)	LP in France and Germany at industry-level ▪ Tariff rate in Canada and Mexico (instrument for competition) ▪ China importation growth (instrument for competition) ▪ Industry and time dummies	between competition and innovation in markets with well-defined intellectual property rights

Continued on next page …

TABLE A1. STUDIES' CHARACTERISTICS AND MAIN CONCLUSION: COMPETITION, INNOVATION AND PRODUCTIVITY (continuation)

Authors	Country, period, sector, data and methodology	Measuring competition	Dependent variable	Explanatory variable	Main conclusion
Amin (2015)	▪ India ▪ 2006 ▪ Retail stores ▪ World Bank's Enterprise Surveys ▪ OLS and IV regressions	▪ Entrepreneur self-perception about the pressure/influence of domestic competitors on influencing product prices. The answer is on a scale 1–4 where (1) means not at all important and (4) important.	▪ Labour productivity (sales per employee)	▪ Competition ▪ Firm size and age ▪ Using computer for management ▪ Inventory system ▪ Owner gender ▪ City and store-type fixed effects ▪ Institutional environment	▪ Positive impact of competition on the level of labour productivity ▪ Competition reveals endogeneity depending on citizen and retail characteristics
Friesenbichler and Peneder (2016)	▪ Eastern Europe and Central Asia ▪ 2012/2013 ▪ All industry sector - NACE two-digit industries ▪ World Bank's Enterprise Surveys ▪ Three-stage least-square estimations (3SLS)	▪ Entrepreneur self-perception about the number of competitors for the principal product/service in the main market.	▪ R&D expenditure ▪ Innovation outcome (product or process) ▪ Competition ▪ Productivity (sales per employee, Value added per employee and Multi factor productivity)	▪ Technological regime ▪ Firm size and age ▪ Export status ▪ Employee's level of education ▪ Ownership ▪ Political instability	▪ Inverted-U shaped impact of competition on R&D ▪ The amount of R&D expenditure increases the probability of successful innovation ▪ Successful innovations consistently reduce the perceived number of competitors ▪ Competition and innovation have a positive impact on productivity
Crowley and Jordan (2017)	▪ 30 countries in Central and East Europe and East Asia ▪ 2011 - 2014 ▪ Low, medium and high technology industry ▪ Business Environment and Enterprise Performance Survey (BEEP) ▪ Multivariate probit	▪ Entrepreneur self-perception about the number of competitors in the market for its main product	▪ To be engaged in one of four types of innovation	▪ Level of competition (= n° of competitors) ▪ Having invested in R&D or in fixed assets ▪ Receiving public support ▪ Firm characteristics: size, age, domestic or foreign ownership, local or non-local market orientation, size of urban area where implemented ▪ Technological sector and country fixed effect	▪ One average, greater levels of competition are associated with greater innovation. However, this relationship is not linear, pointing to an inverted U-Shaped type. ▪ Dividing the degree of competition in categories (low, medium and high), results show that lower competition levels are not associated with less likelihood of innovation but higher levels of competition can reduce it.
Dhanora et al. (2017)	▪ India ▪ 2006-2013 ▪ Pharmaceutical sector ▪ Indian patent office and government financial database ▪ Fixed and random effects estimation techniques	▪ Lerner index = Ratio of sales less labour cost, electricity cost and raw material cost to total sales ▪ Profitability (robustness check) = Ratio of operational profit to total sales.	▪ Market power (competition)	▪ Patent intensity = ratio of granted patents (total, product or process) to lagged R&D expenditure ▪ Foreign ownership ▪ Firm specific characteristics (advertising, imports of raw materials and disembodied	▪ Total patent intensity, as well as product or process patent intensity have an inverted U-shaped relationship with market power, measured by Lerner index or profitability

	technology and assets	

Source: Authors' own elaboration based on Carlin et al. (2004), Aghion et al. (2005), Okada (2005), Tang (2006), Kato (2009), Soames et al. (2011), Inui et al. (2012), Correa and Ornaghi (2014), Amin (2015), Friesenbichler and Peneder (2016), Crowley and Jordan (2017), Dhanora et al. (2017).

Appendix B. Methodological approach

B1. Estimating Patent Stock

Patent stocks are estimated using the Perpetual Inventory method (PIM). This approach (7) assumes that the patent stock (PS) in t is equal to the number of patent applications (P) in t plus the patent stock in $t-1$, updated to period t by a depreciation rate of capital (δ). We used a depreciation rate for patent application of 15%, the same as normally used for R&D expenditure[40].

$$PS_{it} = PS_{i,t-1}(1 - \delta) + P_{it} \qquad (7)$$

Nevertheless, estimation of the starting point is needed, when the net patent stock value in t-1 for the first year of observation is unknown. In the present study, the first year for which we have information is 2007. So, in year t = 1 (= 2007) the pre-sample accumulation stock is estimated as expressed in equation (8), taking into account the growth rate (g) of patents, as well as the depreciation rate (δ).

$$C_{i,1} = \frac{I_{i,1}}{g+\delta} \qquad (8)$$

B2. Estimating Total Factor Productivity

Total Factor Productivity was estimated using a Cobb and Douglas (1928) production function as expressed in equation (9), where i corresponds to the firm and t period of time. Y refers to firms' production output, measured by the value added (GDP). K and L refer to the inputs, representing respectively physical capital stock and labour stock. A expresses the technology used for producing Y and e the error term, which includes unmeasured factors. α, β, and γ correspond to the parameter of interest. Labour stock is measured by the number of employees and physical capital stock by the net value of fixed assets.

$$Y_{it} = A_t K_{it}^{\alpha} L_{it}^{\beta} e^{u_{it}} \qquad (9)$$

To estimate equation (9), the logarithm form was taken in order to obtain a linear regression (10). The lower-case letters correspond to the logarithms of each variable. The equation (10) also includes NUTS 2 region fixed effect (φ_i), activity sector fixed effect (γ_i) and time fixed effect (τ_t) to measure technological progress.

$$y_{it} = c + \alpha k_{it} + \beta l_{it} + \varphi_i + \gamma_i + \tau_t + u_{it} \qquad (10)$$

The results of the Cobb and Douglas (1928) production function, reported in Table B1, showed as expected a coefficient for labour inputs close to 0.7 and close to 0.3 for capital inputs, revealing that the model correctly predicts the value of technological progress or Total Factor Productivity.

[40] Traditionally, authors (e.g. Hall and Mairesse, 1995) used the value of 15% for the depreciation rate of R&D capital stock.

TABLE B1. RESULTS OF COBB -DOUGLAS PRODUCTION

Variables	Y = Log (added value)
	Model D1
Log (fixed assets)	0.225***
	(0.0200)
Log (n° employees)	0.823***
	(0.0317)
Sector dummy	YES
Region NUTS 2 level	YES
Year dummy	YES
Constant	3.275***
	(0.461)
Observations	5,509
R-squared	0.877
Wald test - H0: All coefficient = 0	192.66 (0.0000)

Source: Authors' own elaboration.
Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1.

APPENDIX C. DESCRIPTIVE STATISTICS

TABLE C1. MEAN, STANDARD DEVIATION, MINIMUM AND MAXIMUM

Variables	Obs.	Mean	Std. Dev.	Min	Max
N° of patent applications	5,886	0.480	3.253	0	134
Patent stock per employee	5,499	0.210	1.220	0	31.43
Competition level	5,886	0.924	0.040	0.543	1
N° of employees	5,499	155.60	499.67	1	9 724
Micro-sized firm	5,499	0.237	0.426	0	1
Small-sized firm	5,499	0.334	0.472	0	1
Medium-sized firm	5,499	0.309	0.462	0	1
Large-sized firm	5,499	0.119	0.324	0	1
Age (n° of years)	5,656	25.48	19.89	0	122
Start-up (0 - 2 years)	5,656	0.059	0.235	0	1
Young firm (3 - 5 years)	5,656	0.074	0.262	0	1
Mature firm (6 - 10 years)	5,656	0.123	0.328	0	1
Old firm (> 10 years)	5,656	0.745	0.436	0	1
Tangible fixed assets per employee (x €1.000)	5,499	283.21	2923.44	0	93,699.82
Salary and wages per employee (x €1.000)	5,475	39.12	896.30	0.014	47,529.70
Total Factor Productivity	5,460	7.015	1.909	1.714	14.362
Labour Productivity (x €1.000)	5,151	70.06	1,668.92	-18,906.5	82,381.66
Receiving national public support for RDI	6,540	0.284	0.451	0	1
Region NUTS 2 level – Norte	6,540	0.413	0.492	0	1
Region NUTS 2 level – Algarve	6,540	0.009	0.095	0	1
Region NUTS 2 level – Centro	6,540	0.300	0.458	0	1
Region NUTS 2 level – Lisboa	6,540	0.246	0.431	0	1
Region NUTS 2 level – Alentejo	6,540	0.018	0.134	0	1
Region NUTS 2 level - Madeira and Açores	6,540	0.014	0.117	0	1

Source: Authors' own elaboration.
Note: All monetary variables are expressed on thousands of euro and constant price (base=2007).

TABLE C2. COLLINEARITY DIAGNOSTICS AND CORRELATION MATRIX

#	Variables	VIF	Correlation matrix						
			1	2	3	4	5	6	7
1	Competition level	1.05	1						
2	N° of employees	1.03	-0.0039	1					
3	Age (N° of years)	1.07	0.1758	0.1419	1				
4	Patent stock per employee	1.21	-0.1000	-0.0488	-0.1131	1			
5	Tangible fixed assets per employee	1.42	-0.1373	0.0017	-0.0238	0.3747	1		
6	Salary and wages per employee	1.21	-0.0176	-0.0040	0.0134	-0.0004	0.3799	1	
7	Receiving national public support for RDI	1.01	-0.0203	0.0427	-0.0529	-0.0272	-0.0190	0.0373	1

Source: Authors' own elaboration.

TABLE C3. LABOUR PRODUCTIVITY BY FIRM SIZE

	All sample	SMEs	No-SMEs
Growth rate of LP	53,65%	91,39%	-209,21%
Growth rate of value added	7,66%	36,73%	-181,20%
Growth rate of Log (value added)	0,80%	0,88%	0,31%
Growth rate of employees	48,72%	9,41%	341,32%
Growth rate of Log (employees)	2,03%	2,27%	0,32%

Source: Authors' own elaboration.

Appendix D. Preliminary analysis: Patent function

Table D1. Results of Poisson regression – N° of patent applications, all sectors and manufacturing industry

Variables	Random effects	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects
	ALL SECTORS					
	Model D1	**Model D2**	**Model D3**	**Model D4**	**Model D5**	**Model D6**
Competition level	1.493	1.916	-	-	-56.70**	-58.69**
	(3.093)	(3.349)	-	-	(25.83)	(26.25)
Competition level (squared)	-	-	-	-	33.25**	34.65**
	-	-	-	-	(14.89)	(15.13)
Δ Competition level	-	-	5.397**	5.476**	-	-
(Growth rate)	-	-	(2.355)	(2.375)	-	-
Year dummy	YES	YES	YES	YES	YES	YES
NACE 2 digits dummy	YES	NO	YES	NO	YES	NO
Region dummy	YES	NO	YES	NO	YES	NO
Constant	-2.674	-	-1.141***	-	22.14**	-
	(2.564)	-	(0.188)	-	(10.70)	-
Observations	5,886	3,672	5,232	3,048	5,886	3,672
Number of id	654	408	654	381	654	408
Log pseudolikelihood	-4 664.47	-3 276.79	-4 078.84	-2 763.90	-4 656.24	-3 268.09
H0: All coefficient = 0	0.000	0.003	0.000	0.001	0.000	0.0015
LR test of alpha=0	0.000	-	0.000	-	-	-

Variables	Random effects	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects
	MANUFACTURING INDUSTRY					
	Model D7	Model D8	Model D9	Model D10	Model D11	Model D12
Competition level	9.725**	9.999**	-	-	66.62	55.63
	(4.426)	(4.575)	-	-	(161.0)	(164.0)
Competition level (squared)	-	-	-	-	-30.70	-24.63
	-	-	-	-	(87.16)	(88.75)
Δ Competition level	-	-	5.867+	6.012+	-	-
(Growth rate)	-	-	(3.884)	(3.919)	-	-
Year dummy	YES	YES	YES	YES	YES	YES
NACE 2 digits dummy	YES	NO	YES	NO	YES	NO
Region dummy	YES	NO	YES	NO	YES	NO
Constant	-8.980**	-	0.412		-35.33	-
	(3.675)	-	(0.803)		(74.48)	-
Observations	3,861	2,286	3,432	1,864	3,861	2,286
Number of id	429	254	429	233	429	254
Log pseudolikelihood	-2 899.36	-2 009.45	-2 508.80	-1 671.80	-2 899.00	-2 009.23
H0: All coefficient = 0	0.000	0.0022	0.000	0.0039	0.000	0.0058
LR test of alpha=0	0.000	-	0.000	-	-	-

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses. Significance level: +p<0.15,*** p<0.01, ** p<0.05, * p<0.1. When fixed-effects model is reported it refers to conditional fixed-effects.

APPENDIX E. PRELIMINARY ANALYSIS: PRODUCTIVITY FUNCTION

TABLE E1. RESULTS OF PANEL REGRESSION MODEL – PRODUCTIVITY FUNCTION (LOG TFP), ALL SECTORS

	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects
Variables	Model E1	Model E2	Model E3	Model E4	Model E5	Model E6	Model E7	Model E8
Log (Competition level)	-0.0442	-0.0475	-	-	-	-	-0.202	-0.202
	(0.122)	(0.123)	-	-	-	-	(0.181)	(0.180)
Log (Competition level - squared)	-	-	-	-	-	-	-0.423	-0.413
	-	-	-	-	-	-	(0.530)	(0.531)
Δ Log (Competition level) in "T"	-	-	0.0831	0.0850	-	-	-	-
	-	-	(0.0677)	(0.0671)	-	-	-	-
Δ Log (Competition level) in "T-1"	-	-	-	-	0.228**	0.229***	-	-
	-	-	-	-	(0.0891)	(0.0884)	-	-
Year dummy	YES	YES	YES	YES	YES	YES	YES	YES
NACE 2 digits dummy	YES	NO	YES	NO	YES	NO	YES	NO
Region dummy	YES	NO	YES	NO	YES	NO	YES	NO
Constant	1.583***	1.894***	1.587***	1.904***	1.535***	1.899***	1.576***	1.885***
	(0.0300)	(0.0114)	(0.00518)	(0.00381)	(0.00401)	(0.00353)	(0.0258)	(0.0126)
Observations	5,460	5,460	4,909	4,909	4,344	4,344	5,460	5,460
Number of id	651	651	651	651	651	651	651	651
R-squared (within)	0.013	0.013	0.0145	0.015	0.022	0.022	0.0136	0.014

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1.

TABLE E2. RESULTS OF PANEL REGRESSION MODEL – PRODUCTIVITY FUNCTION (LOG LP), ALL SECTORS

	Random Effects	Random Effects	Random Effects	Fixed Effects	Fixed Effects	Fixed Effects
Variables	Model E9	Model E10	Model E11	Model E12	Model E13	Model E14
Log (Competition level)	-3.147***	-	-	-3.092***	-	-
	(0.804)	-	-	(0.840)	-	-
Δ Log (Competition level) in "T"	-	-1.432**	-	-	-1.511**	-
	-	(0.590)	-	-	(0.595)	-
Δ Log (Competition level) in "T-1"	-	-	-0.475	-	-	-0.456
	-	-	(0.332)	-	-	(0.328)
Year dummy	YES	YES	YES	YES	YES	YES
NACE 2 digits dummy	YES	YES	YES	NO	NO	NO
Region dummy	YES	YES	YES	NO	NO	NO
Constant	2.506***	3.338***	3.687***	3.256***	3.510***	3.496***
	(0.193)	(0.0370)	(0.0207)	(0.0696)	(0.0197)	(0.0191)
Observations	4,987	4,466	3,939	4,987	4,466	3,939
Number of id	618	616	615	618	616	615
R-squared (within)	0.0263	0.0138	0.009	0.026	0.014	0.009

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1.

TABLE E3. RESULTS OF PANEL REGRESSION MODEL – PRODUCTIVITY FUNCTION (LOG TFP), MANUFACTURING INDUSTRY

	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects
Variables	Model E15	Model E16	Model E17	Model E18	Model E19	Model E20	Model E21	Model E22
Log (Competition level)	-0.0317	-0.0293	-	-	-	-	0.0275	8.84e-05
	(0.115)	(0.114)	-	-	-	-	(0.250)	(0.246)
Log (Competition level - squared)	-	-	-	-	-	-	0.310	0.154
	-	-	-	-	-	-	(1.051)	(1.026)
Δ Log (Competition level) in "T"	-	-	0.0601	0.0623	-	-	-	-
	-	-	(0.0672)	(0.0658)	-	-	-	-
Δ Log (Competition level) in "T-1"	-	-	-	-	0.186	0.188	-	-
	-	-	-	-	(0.147)	(0.145)	-	-
Year dummy	YES	YES	YES	YES	YES	YES	YES	YES
NACE 2 digits dummy	YES	NO	YES	NO	YES	NO	YES	NO
Region dummy	YES	NO	YES	NO	YES	NO	YES	NO
Constant	2.168***	1.944***	2.162***	1.956***	2.157***	1.949***	2.171***	1.945***
	(0.0736)	(0.00943)	(0.0353)	(0.00358)	(0.0357)	(0.00286)	(0.0747)	(0.0132)
Observations	3,691	3,691	3,298	3,298	2,906	2,906	3,691	3,691
Number of id	429	429	429	429	429	429	429	429
R-squared (within)	0.0159	0.016	0.0239	0.024	0.0276	0.028	0.0159	0.016

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1.

TABLE E4. RESULTS OF PANEL REGRESSION MODEL – PRODUCTIVITY FUNCTION (LOG LP), MANUFACTURING INDUSTRY

	Random Effects	Random Effects	Random Effects	Fixed Effects	Fixed Effects	Fixed Effects
Variables	Model E23	Model E24	Model E25	Model E26	Model E27	Model E28
Log (Competition level)	-3.302***	-3.092***	-	-	-	-
	(0.572)	(0.840)	-	-	-	-
Δ Log (Competition level) in “T”	-	-	-1.032**	-1.511**	-	-
	-	-	(0.404)	(0.595)	-	-
Δ Log (Competition level) in “T-1”	-	-	-	-	-0.349	-0.456
	-	-	-	-	(0.353)	(0.328)
Year dummy	YES	YES	YES	YES	YES	YES
NACE 2 digits dummy	YES	YES	YES	NO	NO	NO
Region dummy	YES	YES	YES	NO	NO	NO
Constant	3.523***	3.256***	3.748***	3.510***	3.448***	3.496***
	(0.172)	(0.0696)	(0.182)	(0.0197)	(0.107)	(0.0191)
Observations	3,506	4,987	3,127	4,466	2,749	3,939
Number of id	416	618	415	616	415	615
R-squared (within)	0.0399	0.026	0.0291	0.014	0.0235	0.009

Source: Authors’ own elaboration.

Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1.

Appendix F. Productivity function – Random Effects

Table F1. Results of log-log random-effect regression – TFP and LP, all sectors

	Log (TFP)	Log (TFP)	Log (LP)	Log (LP)
Variables	Model F1	Model F2	Model F3	Model F4
Δ Log (competition level) in "T"	-	-	-1.218**	-1.253**
	-	-	(0.576)	(0.576)
Δ Log (competition level) in "T-1"	0.111**	0.116**	-	-
	(0.0453)	(0.0459)	-	-
Micro sized-firm	-0.526***	-0.526***	0.150*	0.132
	(0.0242)	(0.0243)	(0.0811)	(0.0806)
Small sized-firm	-0.305***	-0.304***	-0.0726	-0.0828
	(0.0202)	(0.0202)	(0.0574)	(0.0577)
Medium sized-firm	-0.154***	-0.154***	-0.0520	-0.0573
	(0.0175)	(0.0175)	(0.0457)	(0.0459)
Log (average salary per employee) in "T"	0.0106	0.0105	0.745***	0.748***
	(0.0135)	(0.0135)	(0.101)	(0.103)
Received national public support for RDI in "T"	0.0108***	-	0.0753***	-
	(0.00283)	-	(0.0179)	-
Received national public support for RDI in "T-1"	-	0.0109***	-	0.0112
	-	(0.00260)	-	(0.0169)
Patent stock per employee in "T-1"	-0.0122***	-0.0120***	0.0902*	0.0913*
	(0.00402)	(0.00399)	(0.0503)	(0.0504)
Log (physical capital per employee) in "T-1"	0.0285***	0.0284***	0.0878***	0.0877***
	(0.00359)	(0.00360)	(0.0195)	(0.0195)
NACE 2 digits dummy	YES	YES	YES	YES
Region dummy	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES
Constant	1.744***	1.745***	2.171***	2.177***
	(0.0440)	(0.0442)	(0.161)	(0.161)
Observations	4,211	4,211	4,379	4,379
Number of id	651	651	613	613
R-squared (within)	0,2741	0,275	0,1695	0,1676
R-squared (between)	0,8852	0,885	0,6328	0,6292
R-squared (overall)	0,8539	0,8537	0,5144	0,5108
Wald test - H0: All coefficient = 0	0.000	0.000	0.000	0.000

Source: Authors' own elaboration.
Note: Robust standard errors in parentheses. Significance level: *** p<0.01, ** p<0.05, * p<0.1.
Results of Wald test and Hausman test refer to p-value. Reference category for firm size is large firm.